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Earthquake forecasting and hazard assessment: a preface

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ABSTRACT Forecasting potentially damaging future earthquakes and eruptions is a basic (and expected) outcome of scientific research. Several kinds of forecast are presently performed by considering different combinations of geophysical, geological, historical information and the scientific debate focuses on feasibility of each kind of methodology and reliabilty of the relevant results.

Key words: seismic hazard, earthquake forecasting, early warning.

Capability of forecasting future events is a benchmark for any mature science and represents the most convincing argument supporting funding requests. In the fields of seismology and volcanology, this aspect is of major importance since prediction of future damaging events represents the basic element for the development of effective practices devoted to risk reduction and emergency planning. The 2011 earthquake in Christchurch (New Zealand) arises again the problem to the scientific community, namely the safety level guaranteed by building codes: people ask for seismic provisions that exclude any damage and this imply to take into account minor and more frequent levels of shaking than usual.

Actually, any destructive seismic event is followed by harsh debates (not restricted to the relevant scientific communities) about the actual feasibility of earthquake/eruptions prediction, their role in saving human lives, etc. The recent central Italy earthquake, that struck the city of L'Aquila and its surrounds in April 2009, killed about 300 people and caused economic losses for tens of billions of euros, is not an exception. In particular, since the main shock was preceded by a seismic sequence lasting several months and by claimed unheeded "predictions", after the event the position of the seismological community was largely debated within and (more dramatically) outside the scientific and academic environment. The social networks and in general the web increased the sharing of information and relevant controversy, due to the fact that this was the first large earthquake in Italy in the Internet era. This is a new aspect in the communication that scientists still have to learn how to carefully handle. On one side, it was stated that earthquake forecasting is at the moment unfeasible and inaccurate; on the other side, public opinion asks accounts for funding of what appears a useless science. A similar situation occurred after the large 1980 destructive southern Italy earthquake (November 23) with dramatic discussions between the Italian scientific community on one side and most part of public opinion supported by some scientists on the other. An outcome of that dramatic controversy was the systematic removal of "earthquake forecasting" issues from Italian scientific meetings and discussions, even because it was considered a discipline poorly rewarding in terms of significant results in few years.

It is matter of fact, however, that the seismological community continuously provides earthquake forecasts, but in a form that most of the citizens (and scientists also) does not recognize as actual "predictions". Seismic hazard maps supporting building code prescriptions actually represent such a "forecast" for the whole Italian area. A number of such maps were actually provided since 1980 (CNR-PFG, 1980; Slejko *et al*., 1998; Albarello *et al*., 2000, 2002; Gómez Capera *et al.*, 2010). The last example of this kind of map for Italy is described by Stucchi *et al*. (2011) and was made available on the web (http://esse1.mi.ingv.it/) before the L'Aquila earthquake. The probabilistic formalization underlying these maps masks their basic aspiration to provide (to forecast) a "reasonable" upper bound for seismic ground shaking in a future time span of the order of tens of years (exposure time). Since public opinion (and unfortunately most of the decision makers) is mainly concerned with "short term" forecasting ("what will happen here in the next few days?"), this kind of predictions appears less intriguing and this obscured the great importance of these outcomes for saving human lives and exposed goods by building earthquake-resistant safe structures. Seismic microzoning maps (see GDL-MS, 2008) represent another example of prediction.

Thus, the actual problem is not "if" earthquake/eruption forecasting is possible, but "what" kind of forecast can be provided by exploiting at best the knowledge made available by most recent seismological research.

In order to put again to the limelight of the scientific debate the problem of forecasting future dangerous events, a devoted session ("Earthquake forecasting and hazard assessment") was thought just few weeks after the L'Aquila earthquake for the 28th National meeting of the "Gruppo Nazionale di Geofisica della Terra Solida" held in Trieste on November 16 to 19, 2009. The main rationale of the session was bridging different methodological issues of the different components of seismological/volcanological research in Italy in the conviction that distinction of long term prediction ("hazard assessment"), short term prediction ("forecasting") and very short term forecasting ("early warning") is actually immaterial except as concerns the different use of available background information and the use of eventual forecasts in the different contexts (years necessary for retrofitting structures, days or hours for evacuating people and organizing emergency, down to few seconds to stop facilities such as trains or energy plants). Identical in the various contexts is the importance of an effective evaluation of relevant uncertainty and their effects on forecast reliability, existence of ex-post validation protocols of each methodology, the full exploitation of all available information in the frame of a coherent, explicit and logically consistent procedure, control of physical consistency of models underlying the different approaches. The session was highly participated and a warm and constructive discussion took place. This special issue of the "Bollettino di Geofisica Teorica ed Applicata" includes papers associated to some of the notes presented during that meeting. These contributions cover different aspects and methodological approaches to the problem of earthquake forecasting.

The "simplest" approach to seismic hazard assessment is purely empirical in that it is based on a the statistical analysis of past seismic history. An example of this purely empirical approach is provided in the first paper of the volume (Albarello, 2012) describing a procedure aiming at the full exploitation of available local macroseismic information concerning past earthquakes (local seismic history) to assess the size and the epicentral distance of potentially damaging future earthquakes. Since minimal assumptions are requested only, this approach provides a bottom-line hazard estimate that could represent a benchmark for more advanced estimates. An example for a semi-empirical approach is presented by D'Amico *et al*. (2012), in line with protocols (the so called Cornell-McGuire approach) adopted for the formulation of the reference seismic hazard map of Italy (Stucchi *et al*., 2011). In this case, statistical analysis of past seismic history is accompanied by geological data relative to geometry of potential seismogenic areas. An important aspect addressed in the paper is the role of epistemic uncertainty relative to seismogenic zoning and ground motion attenuation relationships (GMRs) in the final hazard assessment of south-eastern Sicily. It is evident that GMRs play a major role in this kind on analysis. Thus, checking their feasibility and compatibility with observations is of primary importance. This is the argument of the third paper in the volume (Massa *et al*., 2012), specifically devoted to the analysis of performances of some GMRs in the case of the L'Aquila earthquakes. A semi-empirical approach is also at the basis of a prediction tool for volcanic eruptions of Mt. Etna described by Brancato *et al*. (2012). In this case, information provided by past eruptive history and on-going monitoring are merged in the frame of a Bayesian probabilistic procedure. The ex-post testing described in the paper provides information about the actual feasibility of the proposed procedure and new evidence supporting importance of a multi-parameter monitoring of on-going geodynamic processes responsible for the expected dangerous event.

Many contributions of the sessions pointed out the need of more advanced approach to forecast and hazard assessment able to overcome limitation of the above empirical and semi-empirical approaches. In particular, two aspects are of major concern. The first one is the basic hypothesis of independence of subsequent events that makes memoryless the occurrence of subsequent events. An attempt overcoming such hypothesis is provided by Azzaro *et al*. (2012), where the possible significant impact of alternative time recurrence models (Brownian Passage Time) is evaluated against standard approaches in the case of seismic events occurring in the Mt. Etna area where more significant seismogenic faults can be identified. It can be seen again how adding information (fault location, time lasting the previous event) may significantly affect hazard estimates. In the same direction, but by considering a much larger scale, is the contribution by Mantovani *et al*. (2012) that shows how taking into account long-range dynamical interaction of main seismogenic structures may provide a more detailed image of expected future large earthquakes. This approach, that fully exploits geological/geophysical data in the frame of a coherent geodynamic perspective, also outlines possible role of large scale, high precision geodetic monitoring of the crustal strain field to detect medium/short term perturbations induced by post seismic relaxation and potentially responsible for future seismic events.

The use of non-seismic observations to the monitoring of ongoing seismogenic processes is the bulk of a series of papers included in the last part of the volume. Several attempts are reported in the literature since the 1970s but results are as a whole inconclusive [an extensive review is reported in ICEF (2011)]. A basic difficulty is the lack of shared model of the seismogenic process and related phenomena [extensive discussions on this issue can be found in Mulargia and Geller (2003)], but also of extensive and time-continuing monitoring of the relevant observables at the scale of potential interest. This makes more important the collection of new data and observations and the development of physical model able to account for obtained results. On this regard, to give new impulse to this kind of researches, it is mandatory to clearly separate the problem of short term forecasting (with the relevant social implications) and the scientific problem of characterizing the complex dynamics of seismogenesis. While the first one should to be left in the background at this stage of knowledge, the second one represents a well defined scientific target that should be focused on without pre-determined attitudes. On this regards, a new effort in the direction of systematic and well planned monitoring is mandatory to feed physical and geodynamic modelling.

A multi-parametric monitoring of medium-short term variations of the crustal strain field is described by Petrini *et al*. (2012). In particular, degassing activity at faults zones (CO_2 and Rn) and geochemistry of springs were considered in the eastern Alps as a proxy for monitoring transient tectonic phenomena. Results are preliminary but seems to provide encouraging indications. Different observables were considered by Fidani (2012), who reports a detailed extensive analysis of peri-seismic electromagnetic phenomena ("seismic lights") observed in correspondence of the L'Aquila earthquake in a wide area including the seismogenic fault. A larger area is apparently prone to pre-seismic degassing phenomena (deep originated CO_2) revealed by satellite and field data considered by Bonfanti *et al*. (2012). Both these pieces of evidence suggest the presence of a preparatory area including the seismogenic fault but extended over a much larger crustal volume. However, such evidence is apparently contradicted by very precise strainmetric measurements carried on near L'Aquila in the "Gran Sasso" Laboratory and analysed by Amoruso and Crescentini (2012). These authors convincingly support the idea that no pre-seismic short-term strain perturbation occurred in the focal area but a possibly very small crustal volume (less than 100 km^3 around the hypocenter). Contrasting results provided by the above authors enforces the idea that more efforts are requested in the future to provide new more constraining data and coherent physically phenomenological models to enlighten deep seated seismogenic phenomena and open new perspectives to more effective forecasting tools.

REFERENCES

Albarello D.; 2012: *Design earthquake from site-oriented macroseismic hazard estimates.* Boll. Geof. Teor. Appl., **53**, 7-18, doi: 10.4430/bgta 0035.

Albarello D., Bosi V., Bramerini F., Lucantoni A., Naso G., Peruzza L., Rebez A., Sabetta F. e Slejko D; 2000: *Carte dipericolosità sismica del territorio nazionale.* Quaderni di Geofisica, n. 12, Editrice Compositori, Bologna, 7 pp.

Albarello D., Bramerini F., D'Amico V., Lucantoni A. and Naso G.; 2002: *Italian intensity hazard maps: a comparison between results from different methodologies.* Boll. Geof. Teor. Appl., **43**, 249-262.

Amoruso A. and Crescentini L.; 2012: *Pre-seismic phenomena from continuous near-field strain measurements: a brief review and the case of the 2009 L'Aquila, Italy, earthquake*. Boll. Geof. Teor. Appl., **53**, 169-190, doi: 10.4430/bgta0039.

Azzaro R., D'Amico S., Peruzza L. and Tuvè T.; 2012: *Earthquakes and faults at Mt. Etna (southern Italy): problems and perspectives for a time-dependent probabilistic seismic hazard assessment in a volcanic region*. Boll. Geof. Teor. Appl., **53**, 75-88, doi: 10.4430/bgta0038.

Bonfanti P., Genzano N., Heinicke J., Italiano F., Martinelli G., Pergola N., Telesca L. and Tramutoli V.; 2012: *Evidence of CO_2-gas emission variations in the central Apennines (Italy) during the L'Aquila seismic sequence (March-April 2009).* Boll. Geof. Teor. Appl., **53**, 147-168, doi: 10.4430/bgta0043.

Brancato A., Gresta S., Sandri L., Selva J., Marzocchi W., Alparone S., Andronico D., Bonforte A., Caltabiano T., Cocina O., Corsaro R.A., Cristofolini R., Di Grazia G., Distefano G., Ferlito C., Gambino S., Giammanco S., Greco F., Napoli R., Tusa G. and Viccaro M.; 2012: *Quantifying probabilities of eruption at a well-monitored active volcano: an application to Mt. Etna (Sicily, Italy).* Boll. Geof. Teor. Appl., **53**, 55-74, doi: 10.4430/bgta 0040.

CNR-PFG (Consiglio Nazionale delle Ricerche – Progetto Finalizzato Geodinamica); 1980: *Proposta di riclassificazione sismica del territorio nazionale.* Pubbl. 361, ESA Editrice, Roma, Italy, 83 pp.

D'Amico V., Meletti C. and Martinelli F.; 2012: *Probabilistic seismic hazard assessment in the high-risk area of south-eastern Sicily (Italy).* Boll. Geof. Teor. Appl., **53**, 19-36, doi: 10.4430/bgta0036.

Fidani C.; 2012: *Statistical and spectral properties of the L'Aquila EQL in 2009.* Boll. Geof. Teor. Appl., **53**, 135-146, doi: 10.4430/bgta0034.

Gómez Capera A.A., D'Amico V., Meletti C., Rovida A. and Albarello D.; 2010: *Seismic hazard assessment in terms of macroseismic intensity in Italy: a critical analysis from the comparison of different computational procedures*. Bull. Seism. Soc. Am., **100**, 1614–1631.

GDL-MS (Gruppo di Lavoro Microzonazione Sismica); 2008: *Indirizzi e criteri per la microzonazione sismica.* Conferenza delle Regioni e delle Province Autonome – Dipartimento della Protezione Civile, Roma, 3 vols. and dvd.

ICEF (International Commission on earthquake forecasting for Civil Protection); 2011: *Final Report.* Ann. Geophys., **54**, 315-391, doi: 10.4401/ag-5350.

Mantovani E., Viti M., Babbucci D., Cenni N., Tamburelli C. and Vannucchi A.; 2012: *Middle term prediction of earthquakes in Italy: some remarks on empirical and deterministic approaches.* Boll. Geof. Teor. Appl., **53**, 89-111, doi: 10.4430/bgta0037.

Massa M., Luzi L., Pacor F., Bindi D. and Ameri G.; 2012: *Comparison between empirical predictive equations calibrated at global and national scale and Italian strong-motion data.* Boll. Geof. Teor. Appl., **53**, 37-53, doi: 10.4430/bgta0018.

Mulargia F. and Geller R.J. (eds); 2003*: Earthquake science and seismic risk reduction.* NATO Science series, IV Earth and Environmental Sciences – Vol. 32, Kluwer Acad. Pub., The Netherlands, 338 pp.

Petrini R., Italiano F., Riggio A., Slejko F.F., Santulin M., Buccianti A., Bonfanti P. and Slejko D.; 2012: *Coupling geochemical and geophysical signatures to constrain strain changes along thrust faults.* Boll. Geof. Teor. Appl., **53**, 113-134, doi: 10.4430/bgta0017.

Slejko D., Peruzza L. and Rebez A.; 1998: *The seismic hazard maps of Italy.* Ann. Geofisica, **41**, 183–214.

Stucchi M., Meletti C., Montaldo V., Crowley H., Calvi G.M. and Boschi E.; 2011: *Seismic hazard assessment (2003–2009) for the Italian building code.* Bull. Seism. Soc. Am., **101**, 1885–1911, doi: 10.1785/0120100130.

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